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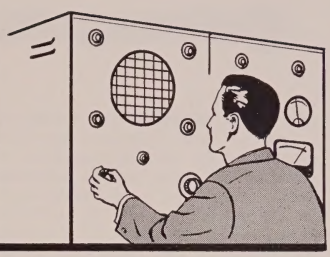

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The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 28, NOS. 9 - 10 SEPT. - OCT., 1958 Subscription By Application Only

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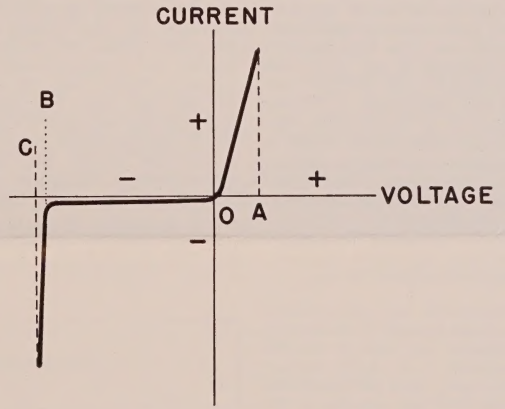
Applications of Zener Diodes

By the Engineering Department, Aerovox Corporation

THE silicon junction diode has opened many new areas of application formerly not fully exploitable with other semiconductor devices. Some of these applications afford considerable circuit simplification.

The special utility of the silicon junction results from its unusual conduction characteristic. Figure 1 shows the general shape of the static volt-ampere characteristic. Note from this plot that the silicon junction exhibits a rather steep forward EI slope from 0 to A, indicating relatively low forward resistance; while the reverse slope from O to B first is quite slight, indicating very high back (inverse) resistance as far as C. Thus, higher front-to-back resistance ratios sometimes are obtainable with silicon than with germanium. In some small silicon junction diodes, the front-to-back resistance ratio at 1 volt may reach 100 million to 1.

The high back resistance disappears beyond Point B. At higher voltages, the reverse current increases sharply, as from B to C, for a small increase in reverse volt-



STATIC CONDUCTION CHARACTERISTIC OF ZENER DIODE

FIG. 1

AEROVOX - - *The Finest In Electronic Components*

Printed monthly by Aerovox Corporation, New Bedford, Mass., U. S. A.

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age. Thus, within a few tenths of a volt the back resistance may fall abruptly from several megohms to a few ohms. (The current increases from a fraction of a microampere to several milliamperes). The extreme steepness of segment BC suggests breakdown of the diode, and is so-termed, but this high-conduction interval is non-destructive, provided the maximum allowable power dissipation of the diode is not exceeded.

Point B is termed the **zener voltage.** Silicon junction diodes may be processed to place the zener point at a desired voltage level. Units so processed are called **zener diodes.** In such commercially available diodes, the zener point (as specified for 25°C operation) may be held as closely as plus or minus 1%. The important characteristic of the zener region (BC) is the high dI/dE, as well as the low E/I quotient. This characteristic gives the diode low d-c resistance and low dynamic impedance and suits it to voltage regulation, peak compression, signal limiting, signal expansion, switching, and similar applications. Zener diodes are available in both low- and high-power ratings and with zener points between 2 and 300 volts.

The features which are of chief interest in the application of zener diodes are (1) the sharp "breakdown" characteristic, (2) the high ratio of resistance between B and C to that between O and B, and (3) the low-resistance and impedance of Region BC. Hence, it is the reverse conduction of the zener diode which is most important in typical applications of this component. The forward characteristic (O to A in Figure 1) seldom is of interest.

Gas-Diode Counterpart

In its operation and applications, the zener diode is seen to be similar to the 2-element gas tube in the following respects. (1) Both devices exhibit extremely high resistance until an applied voltage reaches a given breakdown potential. (2) The breakdown potential can be maintained closely by the manufacturer. (3) The breakdown is non-destructive. (4) Beyond the breakdown point, current increases abruptly. (5) As the current is increased, the voltage drop across the diode remains substantially constant.

The constant voltage drop may be utilized in voltage regulators, compressers, limiters, clippers or slicers, voltage reference units, and voltage standards. The sharp breakdown may be made the basis of wave-shapers, pulse formers, spike generators, switches, and discharge devices.

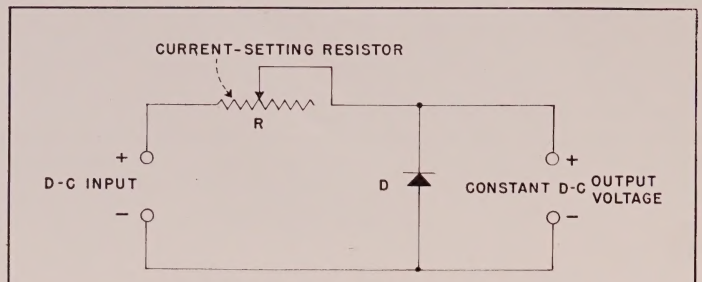


FIG. 2

Gas diodes commonly are available for constant voltage drops from 75 v (Type OA3, VR75) to 150 v (Type OD3, VR150). These tubes may be series-connected for higher-voltage service, however the lower limit remains 75 volts. Less precise operation at slightly lower voltages can be obtained with some neon lamps. The zener diode, on the other hand, can be supplied for constant voltage drops as low as 2 v and as high as 300 volts. Thus, this miniature component not only extends operation to lower levels than those afforded by the gas tube, but also permits high-voltage operation without having to series-connect several units in a regulator string. Still higher-voltage service is, of course, obtainable with the series connection.

The similarity between zener and gas-tube diodes ends with their comparable performance. The gas tube depends upon ionization for its behavior, while the semiconductor diode utilizes field effects upon charge carriers within a semiconductor solid.

Typical Applications

The zener diode finds many applications requiring the constant voltage drop abrupt breakdown which are characteristic of this component. In some applications, the miniature size and mechanical ruggedness of the zener diode give it preference over a gas tube having similar electrical characteristics.

Several typical applications are described in the following paragraphs. These examples will suggest further uses, and they do not exhaust possibilities by any means.

Voltage References. The nearly constant voltage drop across a zener diode biased into its reverse high-conduction region can serve as a standard voltage for calibrating or

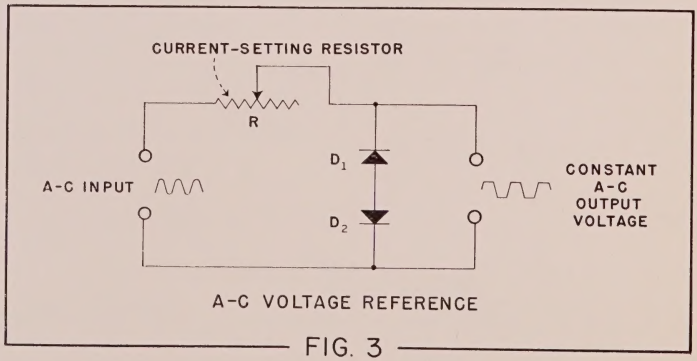


FIG. 3

referencing high-impedance circuits and instruments. The input voltage may be derived from an a-c type power supply.

Figure 2 shows the circuit of a simple d-c voltage reference. The input voltage must be at least 4 times the voltage desired across the zener diode, D. Rheostat R is adjusted initially to set the diode current to the maximum value along the breakdown region (Point C in Figure 1) which may be maintained steadily without exceeding the rated power dissipation of the diode. In its state of high conduction, the diode acts as a low-resistance output element. This provides a fairly "stiff" voltage source. Diode manufacturers are able to supply zener diodes with voltages specified within 1%.

Figure 3 shows a similar circuit for an a-c standard voltage. Here, two zener diodes (D_1 and D_2) are connected back-to-back and act to limit both positive and negative output-voltage peaks to the standard amplitude. Except for the use of two diodes, the circuit is the same as the d-c unit in Figure 2.

The output waveform, also shown in Figure 3, is that of a sharply-clipped sine wave. In addition to other uses, this unit may be employed as a fixed-voltage calibrator for oscilloscopes.

D-C Voltage Regulators. The constant voltage drop across the zener diode operating in its breakdown region may be utilized as a source of regulated voltage. The output voltage is regulated against supply and load variations. The circuit resembles a gas-tube regulator circuit.

Figure 4(A) shows a simple d-c voltage regulator. In this circuit, the value of the current-limiting resistance, R, is chosen to set the diode current to the maximum breakdown value (Point C in Figure 1) which may be maintained continuously without exceeding the rated power dissipation of the diode.

From the breakdown characteristic (Figure 1), it is seen that comparatively large input voltage swings, resulting in large current swings, will change the output voltage developed across diode D only slightly. Similarly, as the external load current increases, correspondingly less current flows through the diode. Good regulation is maintained as long as the diode current does not fall below that corresponding to Point B in Figure 1.

Additional regulation may be obtained by cascading two or more of the simple diode regulators. Figure 4(B) shows a 2-stage regulator. In cascaded arrangements, the unregulated input voltage may need to be

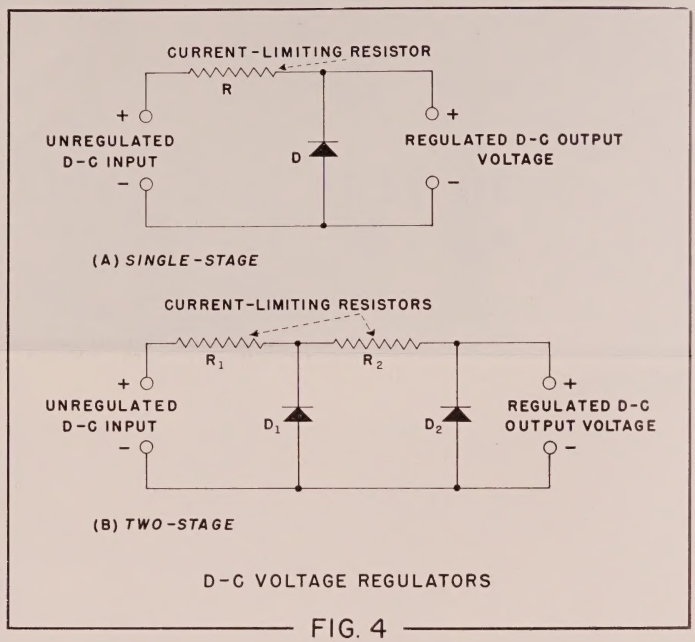


FIG. 4

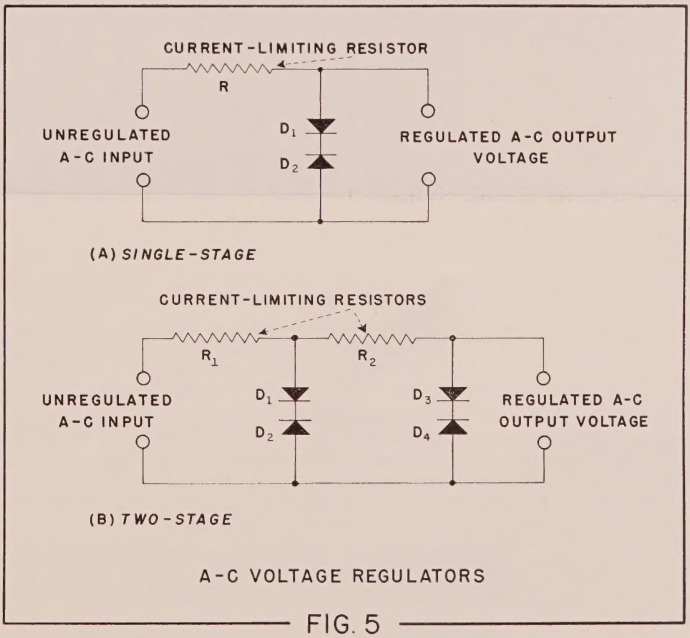


FIG. 5

as much as one order of magnitude higher than the desired output voltage, since voltage division is encountered in the successive regulator stages.

A particular advantage of the diode-type voltage regulator is its ability to function at low voltages. Previously, the simplicity of diode regulation has not been available below 75 v, the lower limit of commercial gas-tube regulators. At the same time, the zener diode regulator may be operated with a single diode, properly chosen regarding type, up to 300 v — and higher with diodes connected in series.

A-C Voltage Regulators. Similar simple arrangements may be employed for a-c voltage regulation.

Figure 5(A) shows a single-stage regulator, and Figure 5(B) a 2-stage cascaded regulator. Note that the only difference between these and the d-c circuits are the double diodes in the a-c units. Thus, in Figure 5 (A), diodes D_1 and D_2 are connected back-to-back to accommodate both a-c half-cycles. In Figure 5(B), each stage of the cascaded regulator contains such diode pairs (D_1-D_2, and D_3-D_4). Either pairs of single diodes or double-anode diodes alone may be used. The output of the a-c regulators is clipped, as shown in Figure 3. The sine-wave shape may be restored to some extent through suitable filtering to remove the harmonics.

Zener Reference Diode in Transsistorized Power Supplies. The simple d-c voltage regulator circuits shown in Figure 4 are suitable only for light- and medium-duty applications, just as the gas-tube regulator is so limited. Furthermore, regulation closer than 5 to 10 percent is not usual.

Heavy-duty, closely-regulated operation at low d-c voltages is afforded by transistorized power supplies. In these units, zener diodes are employed as voltage reference units. Typical transistorized regulator circuits are shown in Figure 6.

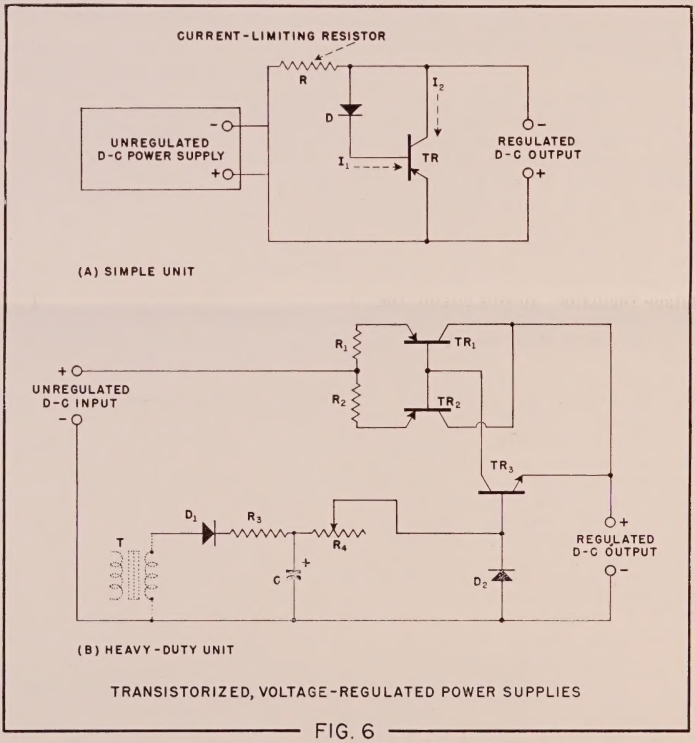
Figure 6(A) is a simple circuit employing a power transistor, TR, as a shunt triode regulator. The base current (I_1) of this transistor passes through the zener diode, D. The anode of this diode is connected to the positive D-C OUTPUT terminal along with the collector of the transistor. Current I_1 therefore is a function of the output voltage. Collector current, I_2, flows in parallel with the external load current.

The current through diode D is adjusted such that this diode normally does not operate in its breakdown region. Current I_1 therefore is quite low. If the output voltage rises, diode D passes heavy zener current into the base of transistor TR. This causes the transistor to draw heavy collector current, I_2, and therefore to lower the output voltage by increasing the voltage drop across the current-limiting resistor. This is the mechanism whereby voltage regulation is obtained.

This scheme may be employed to regulate voltages up to 80 v (depending upon the type of transistor employed) at currents of several amperes. The power supply may be of the semi-conductor type employing germanium, silicon, or selenium rectifiers. Because of the current amplification factor of the transistor, base current I_1 is small compared to collector current I_2. Hence, diode D can be of the low-power type.

A heavier-duty, transistorized regulator circuit is shown in Figure 6 (B). Unlike Figure 6(A), this is a series-type regulator. The two parallel-connected power transistors, TR_1 and TR_2, serve as a voltage-variable series resistor for regulating the output voltage. The low-power transistor, TR_3, samples the d-c output voltage and alters the resistance of the TR_1-TR_2 combination to maintain the voltage at its proper level. The base of transistor TR_3 is held at constant voltage developed by zener diode, D_2. In this application, the diode is comparable to the gas-tube used as a voltage reference in tube-type voltage regulators, the TR_1-TR_2 transistor combination corresponds to the power-type resistance tube, and transistor TR_3 is comparable to the d-c amplifier ("voltage-sensing" feedback tube).

The zener current for diode D_2 is obtained from transformer T (or a winding on the power transformer of the supply unit). D_1 is a diode or semiconductor rectifier of the conven-



TRANSISTORIZED, VOLTAGE-REGULATED POWER SUPPLIES

FIG. 6

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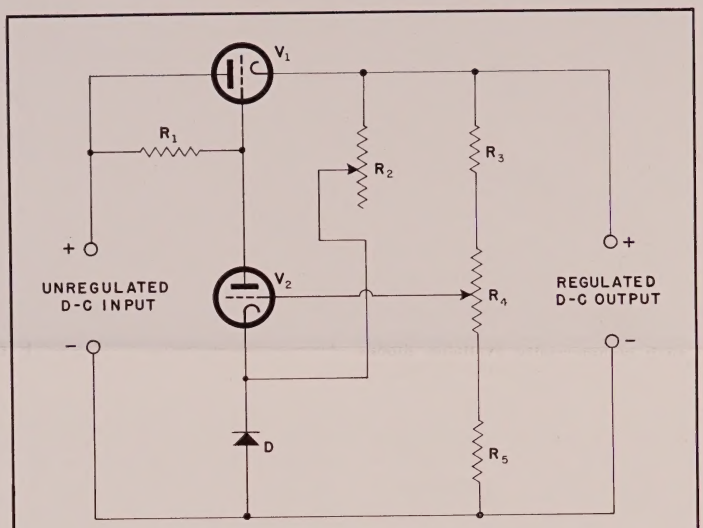
tional type for conversion of the input voltage to dc. Filtering action is provided by resistors R_3 and R_4 and capacitor C. The current through diode D_2 is limited by R_3 and R_4 to the maximum zener value which may be handled without exceeding the rated power dissipation of the diode.

Zener Reference Diode in Tube-Type Power Supply. A zener diode may be employed, in place of the usual gas tube, as the voltage reference device in a conventional voltage-regulated d-c power supply. This substitution can result in a substantial saving of space, since the diode is many times smaller than the tube. Furthermore, the diode requires no socket.

Figure 7 shows such a connection in a conventional d-c voltage regulator circuit. Here, the constant voltage drop across the zener diode, D, furnishes the voltage reference for the cathode of tube V_2. Zener current through the diode is set initially by adjustment of rheostat R_2, and the regulated d-c output voltage is continuously variable by adjustment of potentiometer R_4.

This regulator circuit is seen to be standard in every respect except the substitution of diode D for the usual gas tube.



DIODE VOLTAGE REFERENCE
IN TUBE-TYPE D-C POWER SUPPLY

FIG. 7

Zener Diode as Protective Device. Figure 8 shows how a zener diode may be employed as an overload protective device for d-c circuits and components.

The diode is connected across the d-c terminals of the device to be protected. The polarity must be such trat the diode is reverse-biased; that is, anode negative and cathode positive. Connected in this way, the diode resistance is many megohms and will not disturb operation of the device.

If the voltage of the device rises to the zener point, the diode will conduct heavily, absorbing the extra current which otherwise would pass through and damage the device. The lowered resistance of the diode will reduce the device voltage if the d-c supply is not regulated. When the voltage falls to a lower, safe value, the diode conduction comes out of the zener region and the diode resistance returns to its former high value.

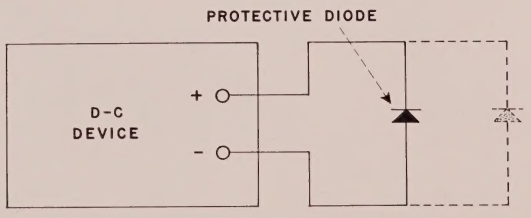
The diode must be chosen for a zener voltage corresponding to the maximum voltage which may be applied safely to the device which is to be protected. If the current drawn during the protection interval is too high for a single diode, several additional diodes may be connected in parallel, as indicated by the dotted lines in Figure 8.

Some of the d-c devices which may be protected in this manner include relays, lamps and other filaments, meters, and recorders.

Limiter, Clipper. The circuit given in Figure 4(A) may be employed as a signal limiter when an a-c signal is applied to its input terminals. With the diode connected as shown, the action will be positive peak-limiting. When the diode is reversed, negative peak-limiting will be obtained.

Similarly, the current given in Figure 5(A) may be employed as a clipper for limiting both positive and negative peak amplitudes.

The zener diode limiter and clipper circuits have the advantage, over similar circuits employing conventional diodes, that no bias batteries are required. Either pulse or sinusoidal signals may be limited or clipped with these circuits.



ZENER DIODE AS D-C PROTECTIVE DEVICE

FIG. 8

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